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SOME COMPUTED EFFECTS OF DOME SKIN AND TEMPERATURE DIFFERENTIAL ON OPERATION OF THE AN/SQS-26 SONAR EQUIPMENT (U)

Prepared for

The Bureau of Ships
Code 688E

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Contract NObsr-91039
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TRACOR, INC. 1701 Guadalupe St Austin 1, Texas

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This technical note contains partial results of a series of studies performed for the SOFIX Program management.

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SOME COMPUTED EFFECTS OF DOME SKIN AND TEMPERATURE DIFFERENTIAL ON OPERATION OF THE AN/SQS-26 SONAR EQUIPMENT (U)

I. INTRODUCTION

An analytical investigation of limited extent has been conducted to obtain estimates of the effects on AN/SQS-26 sonar equipment operation caused by

(a) phase distortion in an incident signal resulting from the passage of the signal through the dome skin surrounding the transducer; and

(b) phase distortion in an incident signal due to a temperature differential existing between the salt water inside the dome and the surrounding sea water.

It was felt that the possible major effects of these phase distortions on operation of the sonar equipment would be manifested in the beam patterns and bearing error in the Sector Scan Indicator (SSI). The SSI bearing error is used in this technical note as a convenient tool for evaluating the operational effects of these phase shifts.

This investigation was carried out in two parts. For expediency, Part I was limited to a study using a two dimensional model, i.e., only the effect of the dome curvature in one horizontal plane was considered. In Part II the study was extended to a three dimensional model. Since it was felt that the complexity involved in including the effects of the dome supporting structure in addition to the dome skin was not warranted in this investigation, only the effect of the dome skin on the received sound signal was considered. A temperature differential of 10°F between water in the dome and the sea was assumed for all cases considered in both Part I and Part II. For convenience in the calculations the water inside the dome was assumed to be isothermal.

The dome skin phase shift and the temperature differential phase shift were computed for relative signal bearings of 30°, 45°, 60°, and 90° in Part I. The phase differences between array-halves (hereinafter termed array-half phase difference) and SSI bearing errors were computed for relative signal bearings of 30°, 45°, 60°, and 90° and are shown in Table I (contained in Section II).

In Part II, the SSI bearing error was computed for the following three cases:

(1) 30° relative bearing, 0° depression
(2) 45° relative bearing, 0° depression
(3) 45° relative bearing, 30° depression

Phase shifts at the individual transducer elements are shown in Table II and the array-half phase differences and SSI bearing error for each of the three cases are shown in Table III (both tables contained in Section III). The SSI bearing error was determined from the array-half phase difference by using the value of 27.0 for the ratio of electrical phase difference to SSI bearing in degrees as determined in another study.[1]

A comparison of the SSI bearing errors computed in Part I (two-dimensional model) with those computed in Part II (three-dimensional model) shows that the latter are somewhat smaller for comparable cases, i.e., same relative bearing and depression angles. These smaller values are attributed to a smoothing effect brought about by the vertical curvature in the AN/SQS-26 dome in conjunction with the vertical stave summing process. This combination acts to reduce the array-half phase difference and thus the SSI bearing error. The two-dimensional results of Part I are included in this report since some sonar domes have little or no vertical curvature (e.g. the AN/SQS-23 dome); thus, the Part I approach is applicable for straight-sided domes even though the

[1] "Some Redundancy Effects on AN/SQS-26 Performance (U)," TRACOR Document No. 63-233-C, Contract NObsr-89265, September 9, 1963, (CONFIDENTIAL).

actual numerical results would undoubtedly be different. It is also of interest to show that instead of increasing the SSI bearing error, the complex curvature of the AN/SQS-26 dome actually acts to reduce it in the specific cases computed in this study.

II. PART I - TWO DIMENSIONAL MODEL

A. Dome Skin Interaction

The phase perturbation of an incident signal by the dome skin was obtained as follows: A plane wave signal was assumed incident on the dome at some relative bearing θ, as shown in Figure 1. A horizontal section of the dome determined by a plane passed through the center horizontal layer of the transducer was divided into segments subtending 5° arcs. (One element face on the transducer is approximately 5° wide.) Each of these segments was then assumed to be a flat plate for which the plane wave has an angle of incidence, θ. The phase shift resulting from passage of the plane sound wave through a flat plate at the appropriate angle of incidence was computed for each of these dome segments using the results of an earlier study.[2] These phase shifts represent the perturbations to the incident wave by the dome skin. The phase shift through a flat plate as a function of the angle of incidence is shown in Figure 2 for selected values of the parameter (ft) where f is the frequency of the sound wave and t is the thickness of the dome skin. One of the curves is for an ft value of 1.75 kc-in, appropriate for the AN/SQS-26.

The phase perturbation at any particular element face due to dome skin interaction was taken to be the phase shift computed at the appropriate dome segment, i.e., the dome segment connected to the element by a ray path. For instance, the phase perturbation at transducer element No. 1 (see Figure 1) is the phase shift at dome segment No. 12. For the case of $\theta = 60^{\circ}$ this shift is 37.2°. The resulting phase shifts at each transducer element for the cases of $\theta = 30^{\circ}$, 45°, 60°, and 90° are shown in Figures 3,4,5, and 6.

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[2] "Some Guidelines for Sonar Baffle Designs," Contract NObsr-85185, TRACOR, Inc. Report, March 30, 1962 (UNCLASSIFIED).

B. Fluid Temperature Differential Effects

If the salt water within the dome is at a different temperature than the sea, the signal incident on the transducer face will be shifted in phase relative to the signal outside of the dome. Since the transducer dissipates energy during the transmit cycle and some of this energy is absorbed by the water inside the dome it is logical to assume that the water inside the dome is warmer than the sea. For the purpose of this study an isothermal condition was assumed for the water inside the dome. The amount of phase shift at the transducer face due to the temperature differential depends on the travel distance of the signal in the warmer medium. The phase shift φ at any transducer element can be computed from the following relation

$$\varphi = 360 \cdot d \cdot f \left(\frac{1}{C_0} - \frac{1}{C_i} \right)$$

where d is the travel distance from the element to the dome, f is the frequency of the incident sound wave, C_o is the propagation velocity in the fluid outside the dome, and C_i is the propagation velocity in the fluid inside the dome. The phase perturbations at the various elements due to a temperature difference of 10^oF for $\theta = 30^o$, 45^o, 60^o, and 90^o are also shown in Figures 3, 4, 5, and 6.

The total phase perturbation of the incident wave at the transducer face due to the dome skin and the assumed fluid temperature differential is obtained by adding the phase shifts due to each of the effects. The total phase perturbation and SSI bearing error for $\theta = 30^o$, 45^o, 60^o, and 90^o are given in Table I.

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TABLE I

SSI BEARING ERROR DUE TO DOME SKIN AND TEMPERATURE DIFFERENTIAL EFFECTS

SIGNAL RELATIVE BEARING (Degrees)	ARRAY-HALF PHASE DIFFERENCE (Electrical Degrees)	SSI BEARING ERROR (Degrees)
30°	4.2°	0.16°
45°	5.8°	0.21°
60°	3.0°	0.11°
90°	1.0°	0.04°

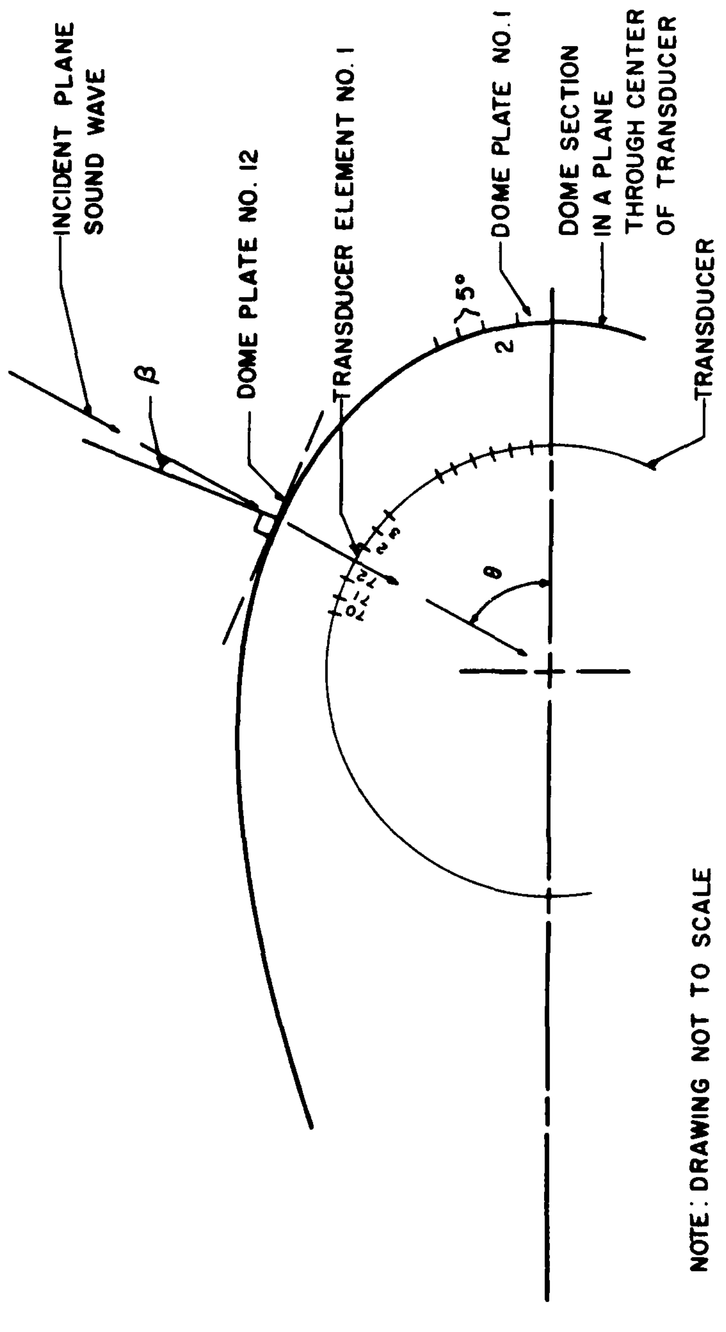

Fig. 1 - GEOMETRY FOR COMPUTING PHASE SHIFT CAUSED BY PASSING A PLANE SOUND WAVE THROUGH THE DOME SKIN; PART I - HORIZONTAL PLANE

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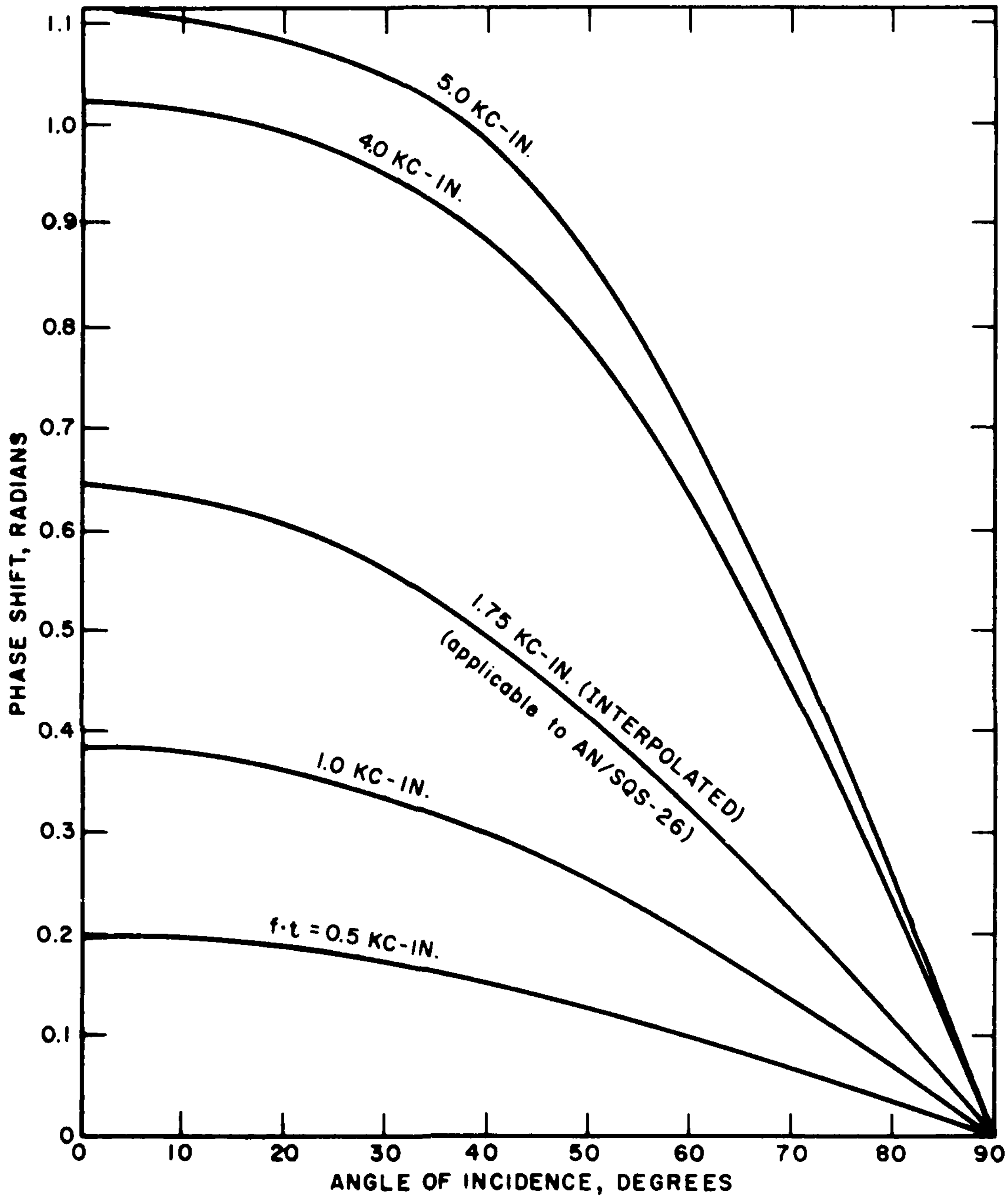

Fig.2 - PHASE SHIFT CAUSED BY PASSING A PLANE SOUND WAVE OF FREQUENCY f THROUGH A FLAT STEEL PLATE OF THICKNESS t IMMERSED IN SEA WATER AS A FUNCTION OF THE ANGLE OF INCIDENCE

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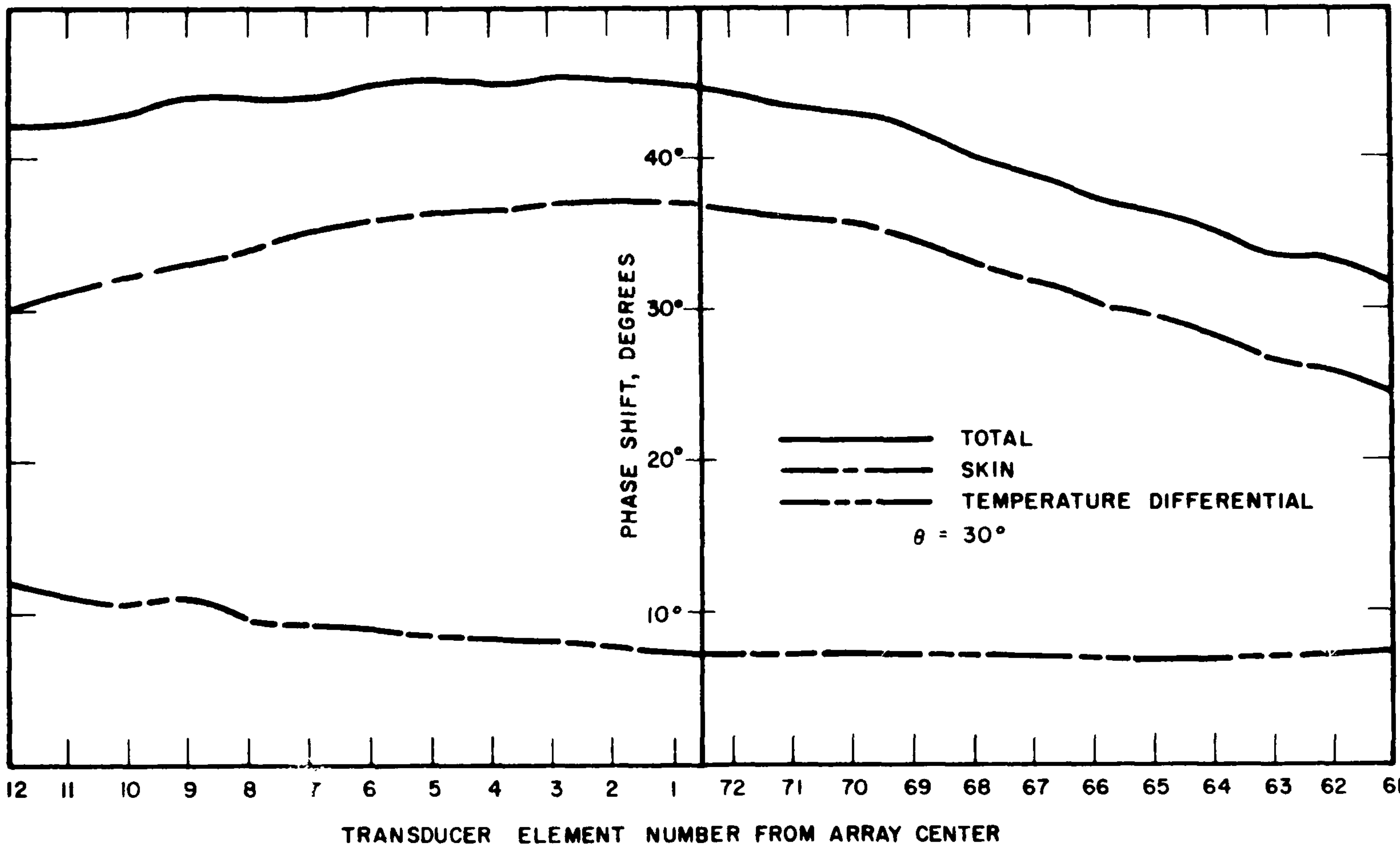

Fig. 3 — PHASE SHIFT CAUSED BY THE DOME SKIN, A 10°F TEMPERATURE DIFFERENTIAL, AND THE TOTAL PHASE SHIFT FOR A SIGNAL BEARING ANGLE θ OF 30° AS DETERMINED BY A TWO-DIMENSIONAL ANALYSIS

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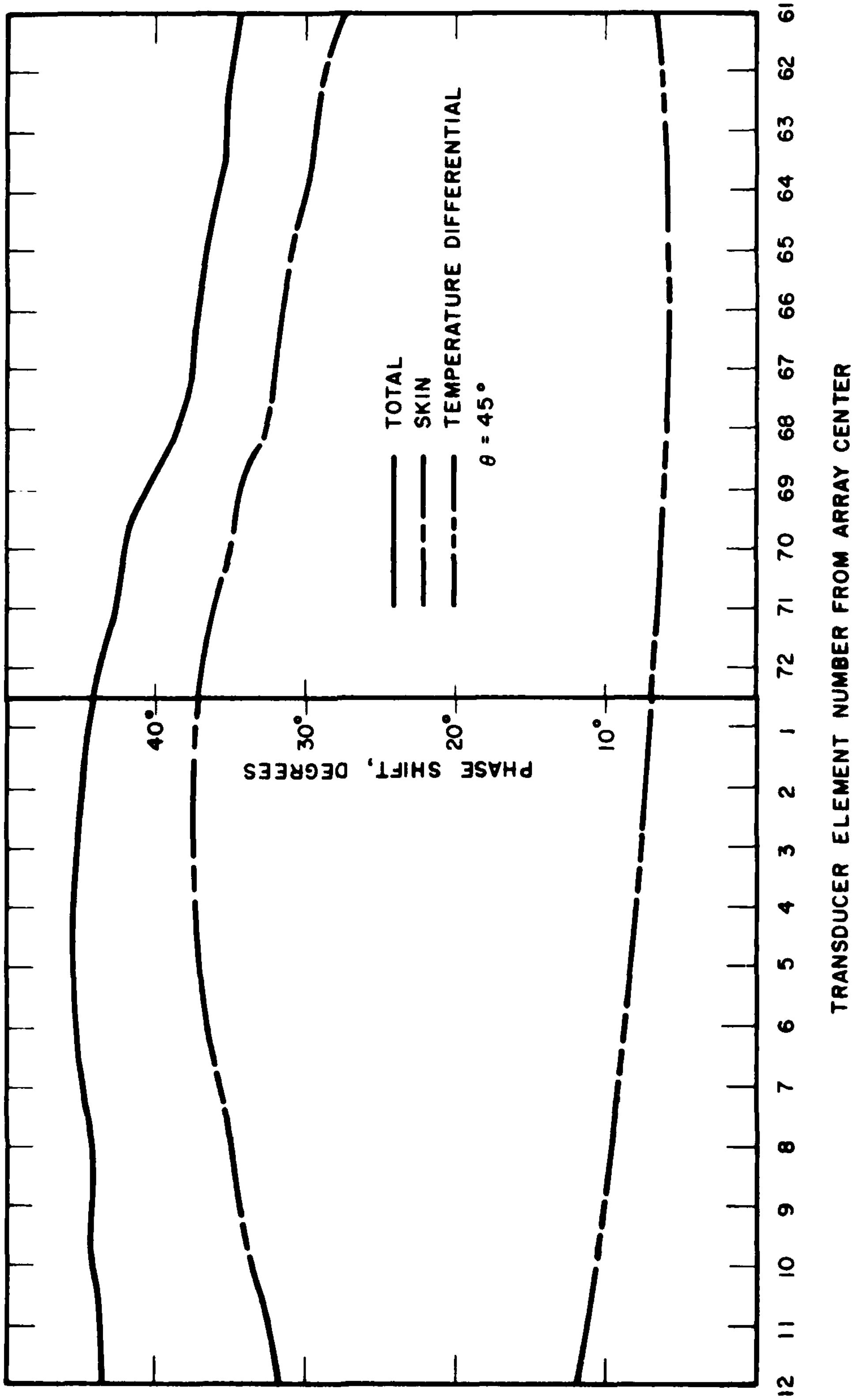

Fig.4—PHASE SHIFT CAUSED BY THE DOME SKIN, A 10°F TEMPERATURE DIFFERENTIAL, AND THE TOTAL PHASE SHIFT FOR A SIGNAL BEARING ANGLE θ OF 45° AS DETERMINED BY A TWO-DIMENSIONAL ANALYSIS

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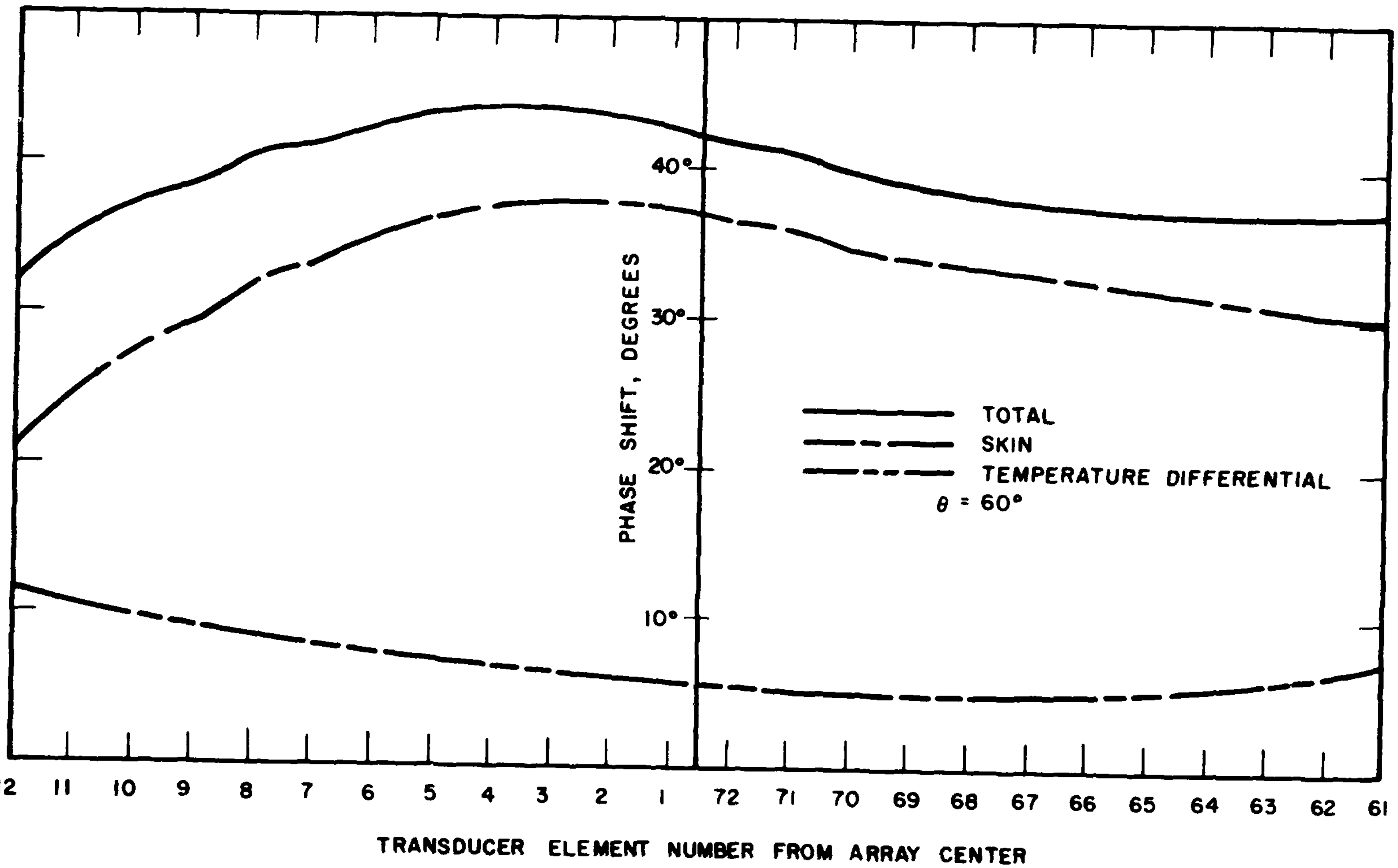

Fig. 5—PHASE SHIFT CAUSED BY THE DOME SKIN, A 10°F TEMPERATURE DIFFERENTIAL, AND THE TOTAL PHASE SHIFT FOR A SIGNAL BEARING ANGLE θ OF 60° AS DETERMINED BY A TWO-DIMENSIONAL ANALYSIS

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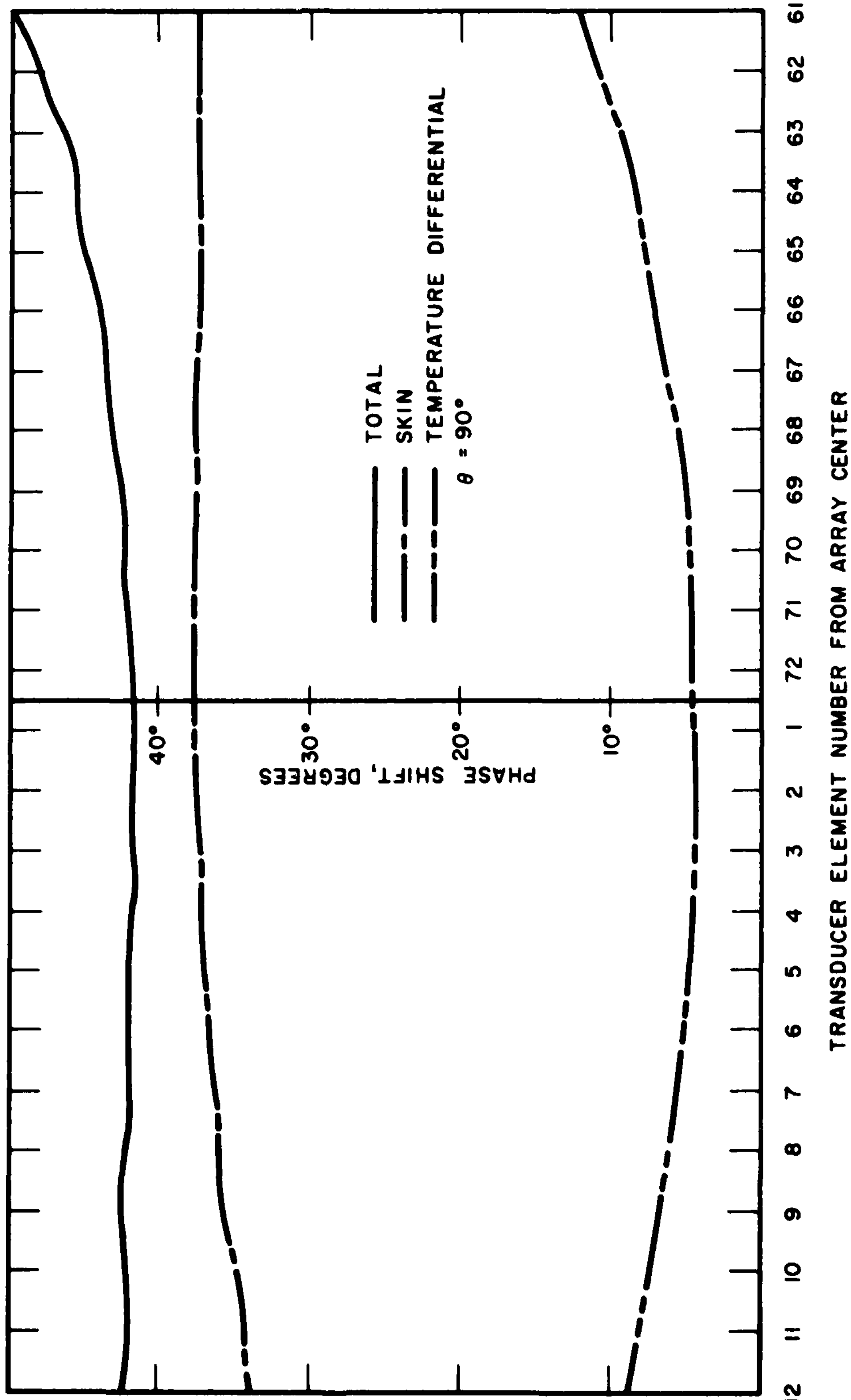

Fig. 6 - PHASE SHIFT CAUSED BY THE DOME SKIN, A 10°F TEMPERATURE DIFFERENTIAL, AND THE TOTAL PHASE SHIFT FOR SIGNAL BEARING ANGLE θ OF 90° AS DETERMINED BY A TWO-DIMENSIONAL ANALYSIS

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III. PART II - THREE-DIMENSIONAL MODEL

A. Dome Skin Interaction

The methods developed in Part I for the purpose of analyzing the phase distortion of the incident signal due to the curvature of the dome in the horizontal plane were subsequently extended to include the effect of dome curvature in the vertical plane. The general discussion in Part I is also applicable here, so only the material unique to the three-dimensional case will be presented in this section.

As shown in the preceding discussion, the magnitude of the phase shift of an incident signal resulting from transmission through the dome skin depends on the angle of incidence of the signal relative to the skin. In order to determine the phase distortion of a signal incident on the dome, the dome was approximated by a series of flat plates approximately one-half wavelength square. The angle of incidence of the signal on each of the plates was then determined; and, from previous work[3], the phase shift of the incident signal resulting from transmission throughout the dome skin was computed. The phase perturbation at any element face due to dome skin interaction was taken to be the phase shift computed at the appropriate dome segment, i.e., the dome segment connected to the element by a ray path.

The angle of incidence of the sound wave on a particular section of the dome was determined as follows:

Consider a plane wave signal incident on the dome at 45° bearing, 0° depression as shown in Figure 7. A ray parallel to the direction of propagation of the incident wave drawn from any element, say element No. 4-10 indicating layer 4 and stave 10 (see Figure 8), intersects the dome skin at a point M. The

[3] See footnote 2.

incident wave makes an angle θ with the normal to the dome at M in the horizontal plane and angle α with the dome at M in the vertical plane. The true angle of incidence ϕ of the plane wave on the dome at M is

$$\phi = \arctan \sqrt{\tan^2 \theta + \tan^2 \alpha}.$$

B. Fluid Temperature Differential Effects

The method used in Part I for computing the phase shift caused by a temperature differential between salt water inside the dome and the surrounding sea water was also used in this phase of the study. A temperature differential of $10^{\circ}F$ was assumed for all of the cases considered in Part II. Again, the water in the dome was assumed to be isothermal and warmer than the sea.

C. Array Phase Difference and Bearing Error

In order to determine the array-half phase difference at any particular signal relative bearing, the phase shift in the incident signal due to the dome skin and temperature differential was calculated at each of the 192 elements involved in forming a beam in that direction. The phase shift at each element is shown in Table II for each of the three cases considered. The element responses were first summed by staves and then the stave responses were summed in an azimuthal plane. The summed stave responses are shown in Figures 9, 10, and 11. The computed array-half phase difference and SSI bearing error due to the dome skin for each case considered in Part II is given in Table III. The array-half phase difference and bearing error due to both the dome skin and temperature difference is given in Table IV.

In trying to analyze the effect on equipment operation of the phase shift produced by the dome skin and the temperature differential, one point must be kept clearly in mind. The effects are not caused by the magnitude of the phase shifts, but rather by the variation in the phase shifts (wave front distortion) across the transducer array. For example, a constant phase shift (which could result from passing a wave through a flat plate of constant thickness) across the array would have no influence on equipment operation, either in beam formation or on SSI bearing error. In the AN/SQS-26 equipment, however, the most realistic cases are similar to those shown in Figures 9, 10, and 11 where there is a definite variation in phase shift across the array, but where this variation is significantly less than the average absolute magnitude of the phase shift. The worst case computed shows a phase variation across the array of 13°. It is conceivable that in some cases the variation could be greater, for instance if the water temperature distribution were markedly different from isothermal or temperature differences were much greater than the assumed 10°F. Results of a previous study[4] show that the effect of element and phase tolerances specified for the AN/SQS-26 sonar equipment (±9°) are operationally insignificant if the variations are randomly distributed. Although the phase shift variations due to dome skin and temperature effects are not randomly distributed they are operationally insignificant for the cases computed and should remain so except possibly in extreme cases as discussed above.

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[4] "Some Computed Effects of Phase and Amplitude Tolerances of Transducer Elements and Preamplifiers on Beam Formation and SSI Performance in the AN/SQS-26 Sonar Equipment (U)", TRACOR Document Number 63-242-C, Contract NObsr-89265, 25 September 1963 (CONFIDENTIAL).

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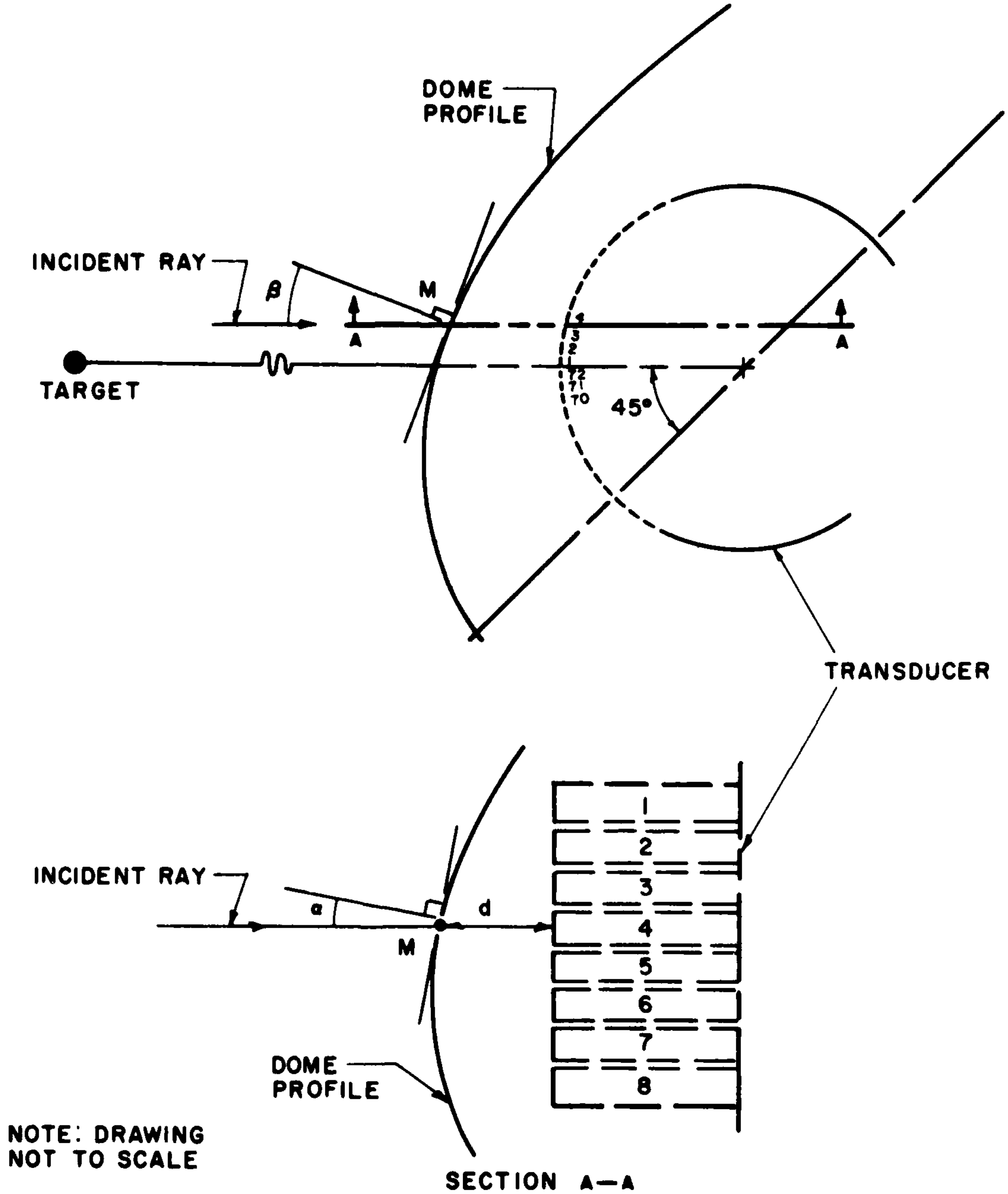

Fig. 7 -GEOMETRY FOR COMPUTING PHASE SHIFT CAUSED BY PASSING A PLANE SOUND WAVE THROUGH THE DOME SKIN; PART II THREE-DIMENSIONAL ANALYSIS

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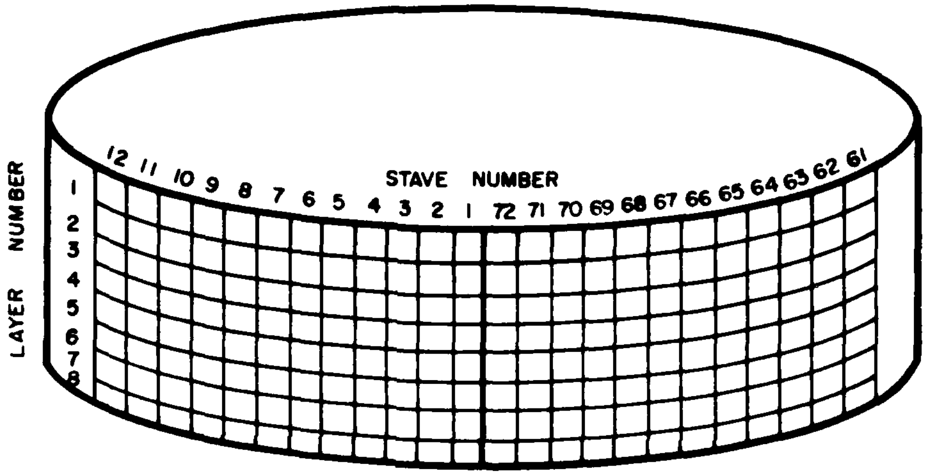

Fig. 8 - TRANSDUCER ELEMENT NUMBERING SCHEME FOR PART II - THREE-DIMENSIONAL ANALYSIS

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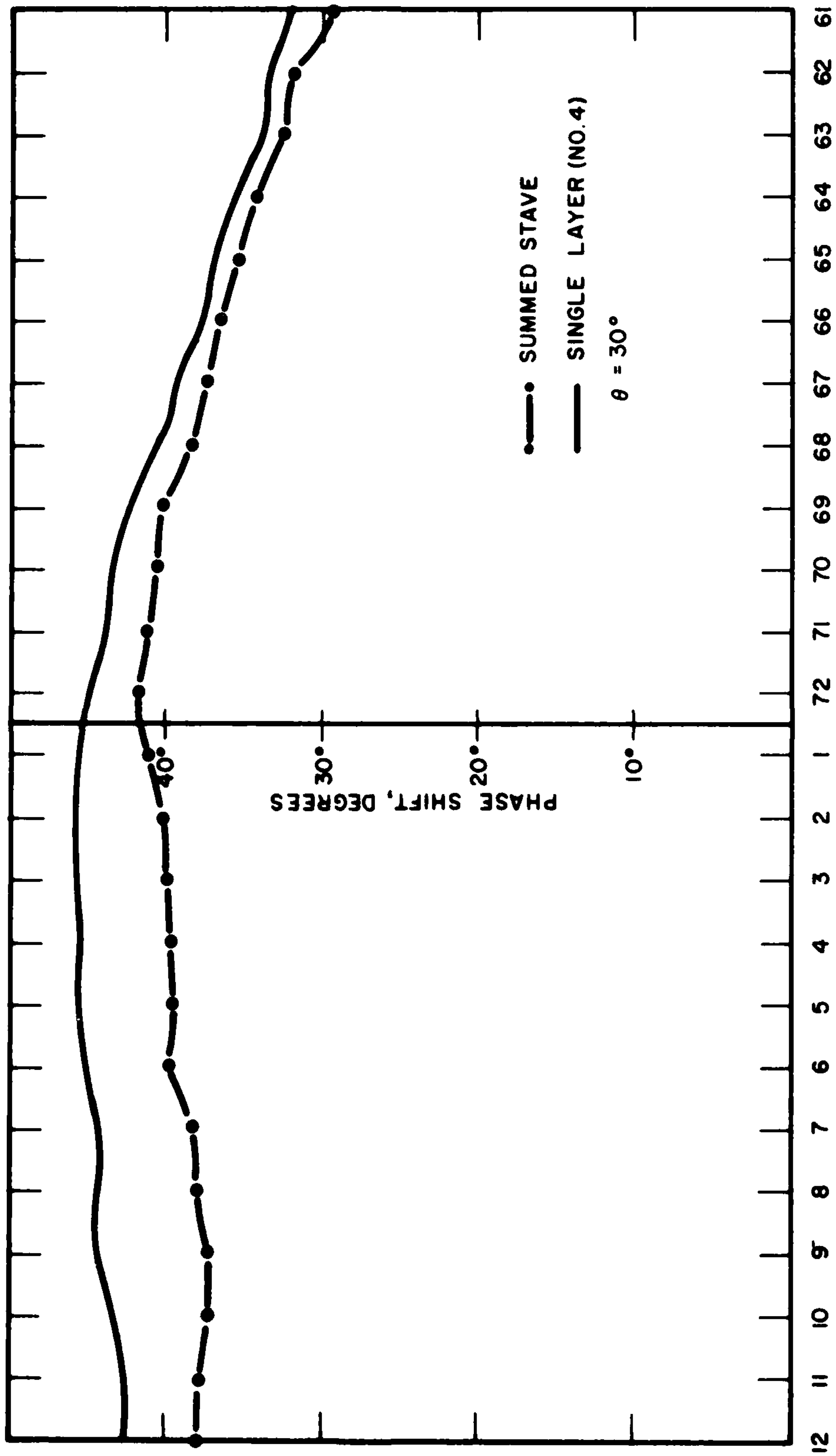

Fig. 9 - STAVE PHASE SHIFT DUE TO DOME SKIN AND TEMPERATURE EFFECTS; 30° BEARING, 0° DEPRESSION

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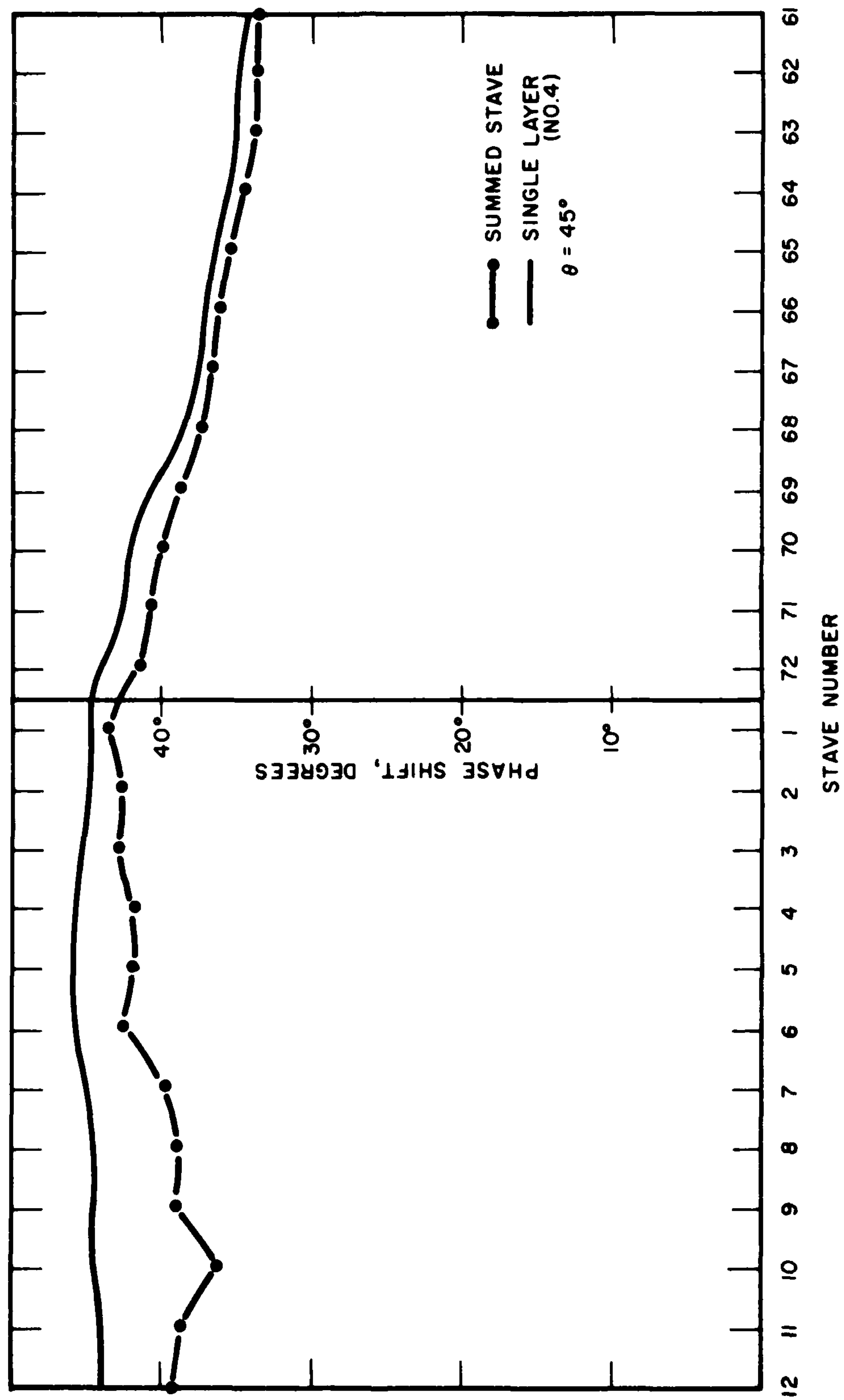

Fig. 10- STAVE PHASE SHIFT DUE TO DOME SKIN AND TEMPERATURE EFFECTS; 45° BEARING, 0° DEPRESSION

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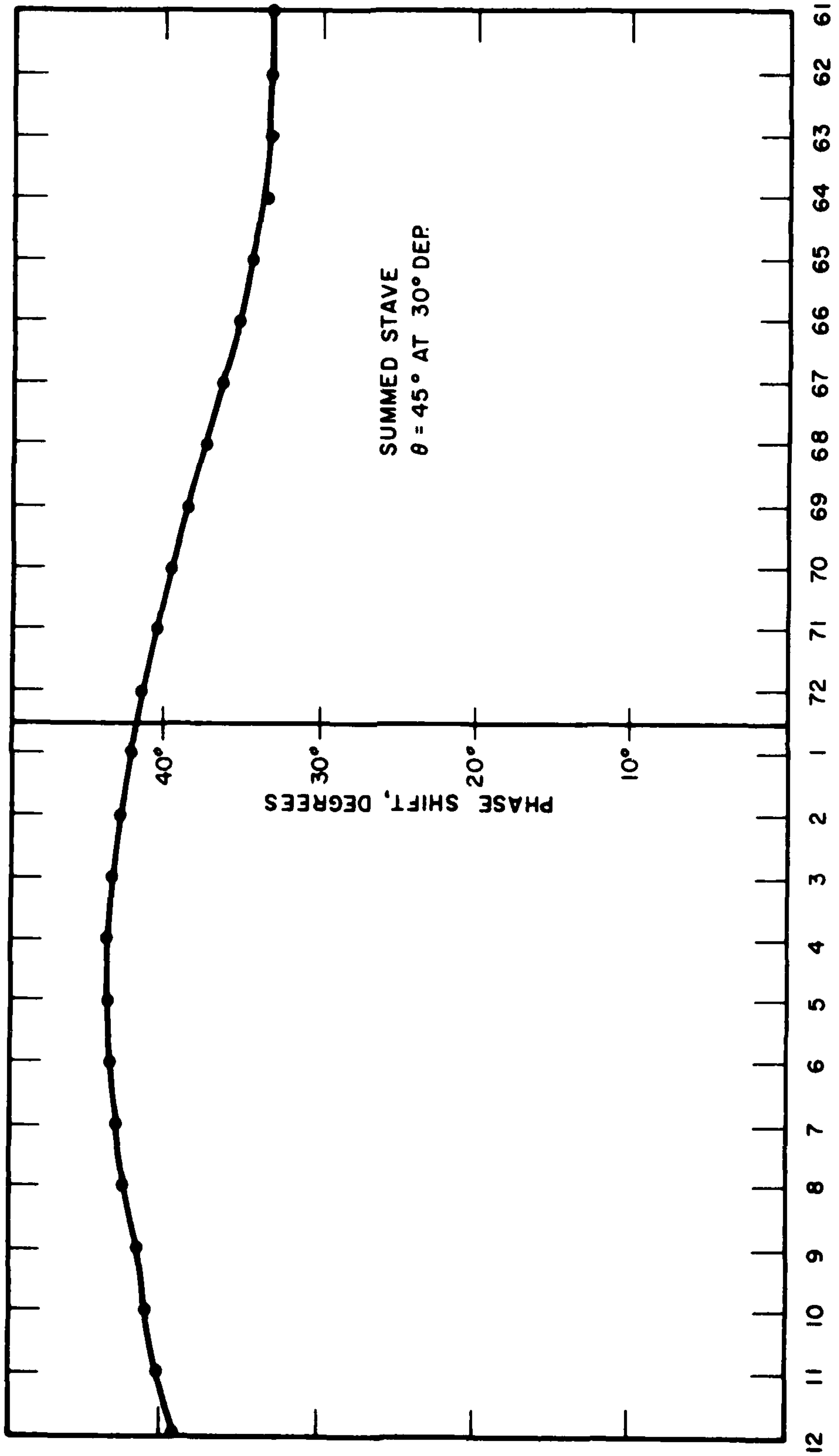

Fig. 11 – STAVE PHASE SHIFT DUE TO DOME SKIN AND TEMPERATURE EFFECTS
45° BEARING, 30° DEPRESSION.

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TABLE II. PHASE SHIFTS AT INDIVIDUAL TRANSDUCER ELEMENTS DUE TO DOME SKIN AND TEMPERATURE EFFECTS

Stave Number → / Layer Number ↓	12	11	10	9	8	7	6	5	4	3	2	1	72	71	70	69	68	67	66	65	64	63	62	61
30° Bearing; 0° Depression																								
1	22°	22°	22°	22°	22°	21°	23°	23°	22°	22°	22°	22°	34°	34°	33°	32°	33°	32°	32°	31°	30°	28°	28°	27°
2	28°	27°	28°	28°	27°	27°	34°	34°	34°	34°	34°	40°	39°	39°	38°	38°	36°	36°	35°	34°	33°	31°	31°	30°
3	22°	22°	40°	40°	41°	42°	42°	42°	42°	42°	43°	43°	42°	42°	41°	41°	39°	38°	37°	36°	34°	33°	33°	31°
4	42°	43°	44°	44°	45°	45°	45°	45°	46°	46°	46°	45°	45°	44°	44°	42°	40°	39°	38°	37°	36°	34°	34°	34°
5	42°	43°	44°	44°	45°	45°	45°	45°	46°	46°	46°	45°	45°	44°	44°	42°	40°	39°	38°	37°	36°	34°	34°	34°
6	22°	22°	40°	40°	41°	42°	42°	42°	42°	42°	43°	43°	42°	42°	41°	41°	39°	38°	37°	36°	34°	33°	33°	31°
7	28°	27°	28°	28°	27°	27°	34°	34°	34°	34°	34°	40°	39°	39°	38°	38°	36°	36°	35°	34°	33°	31°	31°	30°
8	22°	22°	22°	22°	22°	21°	23°	23°	22°	22°	22°	22°	34°	34°	33°	32°	33°	32°	32°	31°	30°	28°	28°	27°
45° Bearing; 0° Depression																								
1	24°	24°	24°	23°	23°	34°	35°	34°	34°	34°	35°	35°	34°	33°	33°	33°	32°	32°	31°	30°	30°	29°	30°	29°
2	33°	33°	33°	33°	33°	32°	39°	39°	41°	41°	40°	39°	39°	38°	37°	36°	35°	34°	34°	34°	33°	32°	32°	32°
3	21°	40°	40°	39°	40°	40°	43°	43°	43°	43°	43°	46°	42°	41°	40°	39°	37°	37°	36°	35°	34°	34°	34°	34°
4	33°	43°	44°	44°	44°	44°	44°	42°	45°	45°	45°	44°	43°	42°	41°	40°	38°	38°	37°	36°	36°	35°	35°	34°
5	33°	43°	44°	44°	44°	44°	44°	42°	45°	45°	45°	44°	43°	42°	41°	40°	38°	38°	37°	36°	36°	35°	35°	34°
6	36°	41°	40°	40°	40°	40°	44°	44°	43°	43°	43°	46°	42°	41°	40°	39°	38°	37°	37°	36°	34°	34°	34°	34°
7	34°	34°	34°	34°	33°	33°	40°	40°	41°	41°	41°	40°	39°	38°	38°	37°	36°	35°	34°	34°	34°	33°	33°	33°
8	33°	33°	33°	33°	33°	32°	39°	39°	41°	41°	40°	39°	39°	38°	37°	36°	35°	34°	34°	34°	33°	32°	32°	32°
45° Bearing; 30° Depression																								
1	45°	44°	42°	42°	42°	42°	42°	41°	40°	39°	38°	38°	33°	33°	32°	32°	31°	30°	30°	30°	30°	30°	30°	30°
2	45°	45°	45°	45°	45°	45°	43°	44°	43°	42°	42°	40°	40°	39°	38°	37°	36°	35°	35°	34°	33°	33°	33°	33°
3	43°	44°	44°	45°	45°	46°	45°	45°	45°	45°	45°	44°	43°	42°	41°	40°	39°	37°	37°	36°	35°	35°	35°	35°
4	41°	42°	43°	44°	44°	45°	45°	45°	45°	45°	45°	44°	43°	42°	41°	40°	39°	38°	37°	36°	35°	35°	35°	35°
5	38°	40°	41°	42°	43°	44°	44°	45°	45°	45°	44°	44°	43°	42°	41°	40°	39°	38°	37°	36°	35°	34°	34°	34°
6	36°	38°	39°	40°	41°	42°	43°	43°	44°	44°	43°	43°	42°	41°	40°	39°	38°	37°	36°	35°	34°	33°	33°	33°
7	32°	35°	36°	38°	38°	40°	41°	41°	42°	42°	41°	41°	40°	39°	39°	37°	37°	36°	34°	32°	32°	31°	31°	31°
8	29°	41°	32°	33°	35°	37°	38°	39°	39°	39°	39°	38°	38°	37°	36°	35°	34°	33°	31°	30°	29°	29°	29°	28°

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TABLE III

SSI BEARING ERROR DUE TO DOME SKIN EFFECT ONLY

	ARRAY-HALF PHASE DIFFERENCE (Electrical Degrees)	SSI BEARING ERROR (Degrees)
30° Bearing 0° Depression	1.07	0.04
45° Bearing 0° Depression	0.75	0.03
45° Bearing 30° Depression	2.97	0.11

TABLE IV

SSI BEARING ERROR DUE TO DOME SKIN AND TEMPERATURE DIFFERENTIAL* EFFECTS

	ARRAY-HALF PHASE DIFFERENCE (Electrical Degrees)	SSI BEARING ERROR (Degrees)
30° Bearing 0° Depression	0.98	0.04
45° Bearing 0° Depression	3.41	0.13
45° Bearing 30° Depression	5.30	0.20

*Temperature differential of 10°F

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IV. CONCLUSIONS

The results of this limited investigation may be summarized by the following conclusions:

1) Phase shifts produced by the dome skin are systematic (do not change with time), so that bearing errors and beam distortion caused by these phase shifts can conceivably be taken into account in equipment calibration.

2) Phase shifts produced by the assumed 10^{o}F temperature differential from outside to inside the dome are generally less than those caused by the dome skin. In actual operation, there will be a transient temperature gradient within the dome which may increase the variation in the phase shifts to some extent. Also, the actual temperature difference may be significantly different from the assumed 10^{o} F.

3) For the few cases considered in the three-dimensional study (Part II), the combined effects of the dome skin and the assumed 10^{o}F temperature differential from outside to inside the dome produces computed SSI bearing errors up to about 0.20^{o}, which would be essentially unmeasurable in practice.

4) Computations of beam pattern distortion caused by the phase shifts due to the dome skin and temperature differential were not made. However, judging from the results of a previous study (see Footnote 4), the effects on the pattern would be operationally insignificant.

5) Since the SSI bearing errors computed in the three-dimensional study are less than those computed in the two-dimensional study, for comparable cases it may be concluded that for these cases the complex curvature of the AN/SQS-26 sonar dome and the vertical beam-forming process act together to produce a smoothing effect and thereby reduce the SSI bearing error.